Appendix A: WASP Analysis Tools Task Memos

Task Memo #1: Development Platform for WASP Analysis Tools

Submitted by:
Integrated Decision Support Group, CSU

1.0 Background

This task memo will discuss the reasons for developing a Water Quality Analysis Simulation Program (WASP) version 5 analysis tools on a Windows 95/98/NT platform.

WASP5 is used primarily by many government agencies and private consultants to model water quality parameters in streams, one of these agencies is the United States Department of Interior, Bureau of Reclamation. The following general description is from http://www.epa.gov/epa_ceam/wwwhtml/wasp.htm.

> Water Quality Analysis Simulation Program, WASP5 is a generalized framework for modeling water quality and contaminant fate and transport in surface waters. Based on the flexible compartment modeling approach, WASP can be applied in one, two, or three dimensions. WASP is designed to permit easy substitution of user-written routines into the program structure. Problems that have been studied using the WASP framework include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination.
>
> Two WASP models are provided with WASP5. The toxics WASP model, TOXI5, combines a kinetic structure adapted from EXAMS2 with the WASP5 transport structure and simple sediment balance algorithms to predict dissolved and sorbed chemical concentrations in the bed and overlying waters. The dissolved oxygen/eutrophication WASP model EUTRO5 combines a kinetic structure adapted from the Potomac Eutrophication Model with the WASP5 transport structure to predict DO and phytoplankton dynamics affected by nutrients and organic material. WASP has been used to simulate the water quality and pollutant fate for a variety of aquatic systems. It is used primarily to investigate the water quality response to management actions, primarily point and nonpoint source load reduction. It is presently being distributed by SEAM and its status is "in-use."
>
> The technical contact is:
>
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Current methods for preparing WASP5 input files are cumbersome and in some cases become the major task of a water quality modeling project. The WASP Analysis Tools being developed for this project will provide tools for preparing water quality data to create WASP5 input files and tools for setting up the network and running the model using graphical interfaces. The Analysis Tools also have interfaces for managing simulation runs and generating reports from WASP5 model runs.

2.0 Cost and Market Share

Past development on UNIX based platforms has been extremely valuable in defining the capabilities of modeling tools, and in some cases is a better development environment. However, with the current trends of hardware pricing and the increased market share of Personal Computers (PCs), the desirability of software developed on Windows 95/98/NT platforms is increasing.

The UNIX and PC worlds have coexisted since about 1982, but it has only been within the last few years (faster PCs with more capabilities) that the advantages of developing research tools in UNIX has decreased. The Windows 95/98/NT platforms are much more stable than previous versions of Windows, and packages for software development have substantially increased their capabilities. Perhaps the strongest reason, however, is the significant price advantage that PC's have over conventional UNIX workstations; when one looks at the cost to benefit ratio, the advantages of UNIX become insignificant for a large segment of developers and users.

A general rule is that UNIX based WorkStations cost more than twice the price of windows based PCs. Though price is an important concern, the availability of supported software such as word-processors, spreadsheet programs, database utilities, and graphing programs is probably the most important reason for the increased market share.

3.0 Development in WASP's "Native" Platform

The minimum hardware and software requirements for WASP5 are a 386 processor, 3 Megabytes of RAM, and the DOS operating system. Though WASP5 is written in FORTRAN and can be easily ported to a UNIX platform, the majority of users run the model on window based PCs. Therefore, the availability of tools such as Excel and Access for graphical and database features can be expected to be available on many of the computers currently running WASP (or the cost of buying these tools is small). The long-term usability and maintainability of the input processor for WASP will be better in the native platform of Windows 95/98/NT.

The goal of this project is to develop a simple and available tool that could be used within the context of current users of WASP. Therefore, there are distinct advantages to staying with the native development of WASP, i.e. a windows based PCs.

4.0 Learning Curve and Application of X Servers on a Window Based Platform

An additional option that was considered in order to use previously developed GUI code was to use an X server on a windows based PCs. This approach was considered to allow X applications to be ported from a UNIX environment to a windows environment. The problem with this approach is that additional software would be required for each user of the WASP input processor. This software would not be expensive to purchase, but could be difficult to install. At the present time this technology is just being developed and the present X servers are slow and the installation and management of the software is complicated. Also, the long term future of these servers is not well defined.

5.0 Moving UNIX Applications to Window Based Systems

Consequently, as PC's become more popular, the ability to port existing UNIX applications to windows becomes more important in order to take advantage of the large PC user base. Essentially three possibilities exist to accomplish this

1. Migration of the software using Windows versions of UNIX libraries.

2. Rewriting the code to an application programming interface (API) that is common to both systems.
3. Rewriting the code to a native Windows API.

Recompiling of the software using Windows versions of the UNIX libraries probably holds the greatest allure. The most common option for this is SCO's Wintif, a Motif clone for Windows. By compiling and linking against the Wintif and UNIX libraries, a windows executable can be produced with minimal changes in code, although in practice your mileage may vary, especially if the program does not closely conform to the Posix standard. Another advantage of Wintif is the ability to easily change the look and feel of the application between Windows 95/98/NT, and Motif. The downside is that executables produced in this way still require an X server, which can place a considerable drain on memory and CPU; the program will tend to run slower as well. In addition, the PC must also have TCP/IP installed for the server to run.

The second option is porting to an API that is common to both Windows and UNIX platforms. XVT's Development Solution for C++ is probably the one most commonly used software for this purpose. The XVT package allows code to be moved from PC to UNIX platforms freely. However, because the API is different, there is a learning curve to be dealt with; the time could probably be just as easily spent in learning how to use the Windows API. Perhaps a larger concern is the fact that in putting together a universal API, the lowest common denominator between each one is achieved, which may mean that some functionality is sacrificed. XVT's product is also fairly expensive. In spite of this, if cross-platform development remains a consideration, then this option may still be useful.

A direct port to the Windows API is the third option. This choice ensures that the application will have native look and feel. Its down-sides are similar to the previous one's; time will need to be spent learning the new API, and further program development will require the maintenance of two sets of source files, one for each platform.

6.0 Conclusions

There is no single or easy solution for migrating from a UNIX to a PC platform. Large graphics-intensive programs may be best ported using Wintif; when portability is a primary issue, portable API's like XVT's package may be a better choice; and with software that uses little graphics the developer probably should consider a rewrite of the interface to the Windows API.

New languages that are "platform independent" are being developed and may offer some increased flexibility in the future. Some of these languages include java, tcl/tk, python, and rexx. The current state of these languages looks promising, but it is difficult to determine which language approach will be the standard.

The best approach is to keep the Graphical User Interface (GUI) and application code separate from the model to minimize porting and maintenance. The development platform should be the same as the targeted users of the system. For this project the targeted users are assumed to be using windows based PCs and therefore the development platform is window based PCs.

Task Memo #2: WASP Analysis Tools Funding Opportunities

Submitted by

Integrated Decision Support Group, CSU

1.0 Purpose

This task memo will list the funding opportunities that have been identified to expand the participation in the development of analysis tools for the WASP5 program.

2.0 Research Funding Opportunities

TABLE 1. Research Opportunity List

Agency	Deadline	Name of Program	Potential	Notes
CASI	Late November	Technology Transfer Grants	Fair	These grants must have support from a local business. CSU met with the director of this program to see what support could be generated, but there were no local businesses interested.
DOE	October	Biological and Environmental Research/ Environmental Remediation Research	Ok	These grants do not allow funding for model development and calibration. CSU would need to address a specific problem. Other avenues seemed more promising.
DOE	N/A	Inter-agency unsolicited proposal	Ok	This is a less-formal process and could be very successful if CSU can make a contact within DOE. The project did not have enough appeal to DOE to attempt this option.
EPA/ Research Labs	N/A	Inter-agency unsolicited proposal	Good	This is a less-formal process and could be successful if CSU can make a contact with someone at CEAM.
EPA/ WASP Group	N/A	Inter-agency unsolicited proposal	Very Good	CSU and the Bureau were successful in getting funding for the project for two years.
EPA/ National Level	August	Sustainable Development Challenge Grant Program	Good	CSU looked into developing a project with the south platte water users for a water quality module that could be added into a future DSS. Current focuses of south platte users are with water quantity issues and not water quality. This may be an option for the future.
EPA/ Region Level	N/A	Regional Support for a Project using WASP	Good	CSU made a contact with Gene Kersey, a manager in Region 8. CSU set up a meeting to discuss what they need and a demonstration of some of our projects

TABLE 1. Research Opportunity List

Agency	Deadline	Name of Program	Potential	Notes
Fish and Wildlife Service	February	Wetland Conservation Act/North American Wetlands Conservation Council	Fair	CSU would need to establish an "Important Waterfowl Habitat Area" and put together a team, from the Nature Conservancy, folks at the State, EPA etc. CSU could apply WetScape and develop the wasp component as a water quality module. CSU would need to find a study area that has a specific problem. Other avenues were pursued.
Joint Project with Eric	N/A	A Reclamation, regional project.	Fair	CSU could get some supporting funds for applying WetScape with a wasp module to a region. WetScape was not considered a good link to WASP AT software since the platforms were different.
Nature Conservancy	N/A	Regional and/or State project	Fair	There are no formal process at the state, regional, or national level. CSU has some contacts a both levels.
NFS/EPA	May	Partnership for Environmental Research	Fair	This takes a long time and CSU has been submitting other projects for this grant program.
NFS	November	CISE Postdoctoral Research Associates in Computational Science and Engineering and Experimental Computer Science	Good	These projects tend to be more pure research than applied. No students were found to be interested in pursuing these funds.

3.0 Conclusions

A number of funding opportunities have been identified and joint funding opportunities with the EPA and the Bureau of Reclamation were pursued and has successfully funded this research.

Task Memo #3: River Geometry for California Gulch

Submitted by
Integrated Decision Support Group, CSU

1.0 Purpose

The river geometry of California Gulch was analyzed with the dataset available for the META4 (i.e. Metals) component of wasp, this was done to determine if the dataset is suitable for testing the capabilities of the models. Flow data from the metals file for California Gulch was compared to historical gaging data and field measurements.

2.0 Methods

The input data file has 22 segments and 11 of them are upper or surface segments. These segments will be used to calculate velocities and stream geometry using two different methodologies, the flow data is then compared to historical gage data and field measurements.

2.1 First methodology

The first methodology is based on the outflows from the input file. This outflow is used as a discharge measurement, Q. The discharge measurements are from the Meta4 file created for California Gulch. By using the equations provided in the wasp manual as well as the segment volumes in the input data file velocities, depth, cross-sectional area and length for the 11 segments, different parameters can be calculated, results are shown in Table 1.

TABLE 1. Calculations for Method 1 Analysis of META4 File for California Gulch.

Seg #	**a**	**b**	**c**	**d**	**Q (cms)**	**Vel. (m/s)**	**Area (m^2)**	**Depth (m)**	**Width (m)**	**Length (m)**	**Vol. (m^3)**
1	0.56	0.40	0.27	0.40	0.0142	0.1020	0.1388	0.0492	2.823	136.24	18.91
2	0.56	0.40	0.27	0.40	0.0623	0.1845	0.3377	0.0890	3.796	195.99	66.18
3	0.56	0.40	0.27	0.40	0.0626	0.1848	0.3386	0.0891	3.800	320.49	108.52
4	0.56	0.40	0.27	0.40	0.0425	0.1583	0.2684	0.0763	3.516	387.82	104.08
5	0.56	0.40	0.27	0.40	0.0538	0.1740	0.3093	0.0839	3.687	248.07	76.72
6	0.56	0.40	0.27	0.40	0.1416	0.2562	0.5526	0.1235	4.474	351.18	194.08
7	0.56	0.40	0.27	0.40	0.0821	0.2061	0.3986	0.0993	4.012	343.76	137.01
8	0.56	0.40	0.27	0.40	0.0835	0.2075	0.4027	0.1000	4.026	416.20	167.60
9	0.56	0.40	0.27	0.40	0.0991	0.2222	0.4462	0.1071	4.166	458.46	204.56
10	0.56	0.40	0.27	0.40	0.0765	0.2002	0.3818	0.0965	3.955	343.02	130.98
11	0.56	0.40	0.27	0.40	0.0538	0.1740	0.3093	0.0839	3.687	260.35	80.51

The equations used to calculate the values in Table 1 are from the Wasp 5 manual in Chapter 4 for data group c: volumes on page 15 (These calculations assume a rectangular cross section).

$$V = aQ^b \qquad \text{(EQ 1)}$$

Where:

V = Water velocity within the segment (m/s)
a = Hydrologic coefficient of velocity (value from input file)

Q = Discharge from segment (cms)
b = Hydrologic exponent for velocity (value from input file)

$$D = cQ^d \qquad \text{(EQ 2)}$$

Where:
D = segment average depth (m)
c = hydrologic coefficient of depth (value from input file)
d = hydrologic exponent for depth (value from input file)

Other equations used:

$$Q = V \cdot A \cdot D \qquad \text{(EQ 3)}$$

Where:
Q = out flow from segment (cms)
V = water velocity within the segment (m/s)
A = Cross sectional area (m^2)
D = water depth (m)
W = section width (m)

where:
Q in m^3/s, V in m/s, W& D in m, A in m^2

2.2 Second methodology

In this methodology we used the velocities and the depths that were produced in the wasp output file to calculate the discharge in each segment (once based on water velocity and another based on depth). The discharge measurements are from the META4 file created for California Gulch. Average segment width and segment length results are shown in Table 2.

TABLE 2. Calculations for Method 2 Analysis of META4 File for California Gulch.

Seg#	a	b	c	d	Q (cms)	Vel. (m/s)	Area (m^2)	Depth (m)	Width (m)	Length (m)	Vol. (ft^3)	Vol. (m^3)
1	0.56	0.40	0.27	0.40	0.0175	0.1110	0.1576	0.0537	2.9345	120.01	667.80	18.91
2	0.56	0.40	0.27	0.40	0.0508	0.1700	0.2987	0.0821	3.6380	221.59	2337.00	66.18
3	0.56	0.40	0.27	0.40	0.0627	0.1850	0.3391	0.0890	3.8098	320.06	3832.00	108.52
4	0.56	0.40	0.27	0.40	0.0523	0.1720	0.3040	0.0831	3.6578	342.40	3675.00	104.08
5	0.56	0.40	0.27	0.40	0.0478	0.1660	0.2882	0.0802	3.5935	266.20	2709.00	76.72
6	0.56	0.40	0.27	0.40	0.0978	0.2210	0.4427	0.1060	4.1765	438.38	6853.00	194.08
7	0.56	0.40	0.27	0.40	0.1117	0.2330	0.4793	0.1120	4.2790	285.89	4838.00	137.01
8	0.56	0.40	0.27	0.40	0.0831	0.2070	0.4013	0.0990	4.0537	417.62	5918.00	167.60
9	0.56	0.40	0.27	0.40	0.0989	0.2220	0.4457	0.1070	4.1656	458.94	7223.00	204.56
10	0.56	0.40	0.27	0.40	0.0882	0.2120	0.4159	0.1020	4.0779	314.90	4625.00	130.98
11	0.56	0.40	0.27	0.40	0.0653	0.1880	0.3473	0.0906	3.8339	231.79	2843.00	80.51

The equations 1-3 are used to calculate the values in Table 2 are used to calculate amounts from the output file.

3.0 Comparison of Methods

Field data was collected in October of 1998 to compare with flows used by the META4 input file. Cross-sections were measured in locations assumed from information about the input file generation for California Gulch. A velocity meter was used to calculate the flow from a measured cross-section area, the GPS coordinates were also measured and recorded. Most of the measurements were taken in the lower portion of the Gulch and there were some problems with identifying the original locations of the META4 measurements. The results for all the methods are shown in Table 3.

TABLE 3. Flow data in cubic meters per second for California Gulch.

Seg #	Field	META4	USGS Max.	USGS Min.	USGS Avg.	Method #1	Method #2
1	N/A	0.0142	0.1784	0.0181	0.0433	0.0175	0.0176
2	N/A	0.0623	0.1784	0.0181	0.0433	0.0508	0.0510
3	N/A	0.0626	0.1784	0.0181	0.0433	0.0627	0.0624
4	N/A	0.0425	0.1784	0.0181	0.0433	0.0523	0.0526
5	N/A	0.0538	0.1784	0.0181	0.0433	0.0478	0.0481
6	0.0726	0.1416	0.1784	0.0181	0.0433	0.0978	0.0966
7	0.0571	0.0821	0.1784	0.0181	0.0433	0.1117	0.1108
8	0.0747	0.0835	0.1784	0.0181	0.0433	0.0831	0.0814
9	0.0568	0.0991	0.1784	0.0181	0.0433	0.0989	0.0989
10	0.0528	0.0765	0.1784	0.0181	0.0433	0.0882	0.0877
11	0.0526	0.0538	0.1784	0.0181	0.0433	0.0653	0.0652

Figure 1, "Plot of flow values from different sources.," on page 8 shows the comparison of the flow calculations from the different methods. The USGS gage data is for the confluence of the Arkansas River and is represented by segment 12. As can be seen from Figure 1, "Plot of flow values from different sources.," on page 8, most of the values are within the minimum and maximums for the USGS gage, the gage records are from 9/91 to 9/92.

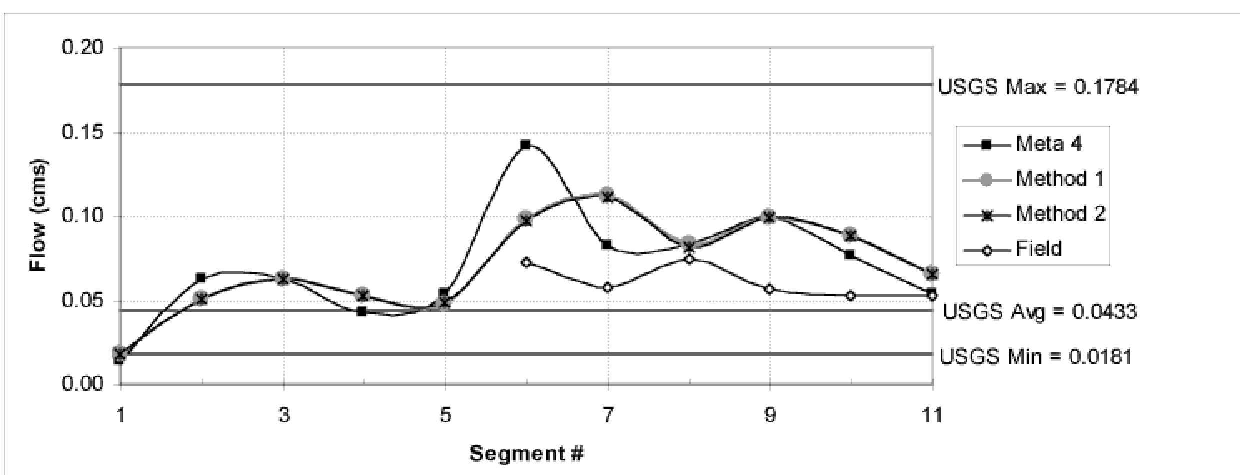

FIGURE 1. Plot of flow values from different sources.

The field data compare with the values from the META4 file, although the exact segments could not be located in the field since there were no specifics given in the data file. From the comparison of the flow values the input and output of the META4 file are nearly exact as can be seen from a comparison of Table 1 and Table 2 and also fit in with the measured flows both in the field and the USGS site.

4.0 Conclusions

The META4 stream geometry would appear to be reasonable based on the flow parameters measured. A more detailed field study would need to be preformed to check the flows in each segment.

Task Memo #4: Performing Sensitivity Analysis on the California Gulch Data Using WASP Builder

Submitted by
Integrated Decision Support Group, CSU

1.0 Purpose

This task memo will describe the sensitivity analysis preformed on the California Gulch dataset (12/4/1994) using the META4 component developed for WASP 5.0. Metal parameters will be used to determine the model sensitivity to changes in inputs such as flow.

2.0 Methods

The focus on this analysis will be on the behavior of the model, it is assumed that the underlying California Gulch dataset is typical of datasets to which META4 is applied. Using the WASP Builder interface multiple model runs were created as percentages of the original California Gulch input file baseline values. The results of the model runs created a massive amount of data with values for each time period and each segment. Therefore the maximum change of individual values for each segment are compare to determine extreme cases and the maximum change in means are compared to determine typical changes and trends. In the 1994, dataset segments 1-11 are for surface water (upper) and segments 12-22 are for the pore or groundwater segments (lower). Therefore the analysis for each group of segments is done separately.

2.1 Simulation length

Initially the length of the simulations was determined to be 10 days with 0.01 day as time step. This simulation length could not be achieved for all the runs because the model in some cases calculates smaller time steps and terminates the run. To solve this problem we let the model calculate the time step. This approach worked fine in some cases (water flow 125% & 150%), but in others the model would not allow values less than the original (volumes 25%, 50%, & 75%).

2.2 Parameter Values

Using the sensitivity analysis window in WASP Builder we applied values for several parameters to perform a sensitivity analysis on META4. The values that were applied were a percentage of the original value (or base case) in 25% increments. Therefore the values considered were 25%, 50%, 75%, 100%, 125%, and 150% of the parameters. As the values of the following parameters were changed, input files were created and run in WASP Builder:

1- Exchanges (area of contact - characteristic length)
2- Segment volumes
3- Surface water flow into and out of segments
4- Pore flow into and out of all segments
5- Waste loads for metals (Cd and Pb)

2.3 Parameter sensitivity

Not all the metal parameters changed in value with response to changes in the variables. WASP Builder has the option in the Report Generator to show only changes in parameter values (i.e. the Select parameters that show differences button). This option only displays values for parameters that are different from the base case, and therefore used for this analysis. Table 1 shows metal parameters that changed based on changes in variables.

TABLE 1. Variables for Sensitivity Analysis

Variables	Metal parameters with values different then the base case
1- Adjusted Flows	Total, Dissolved, Free, Partial Cd(II) in mg/L Total, Dissolved, Free, Partial Pb(II) in mg/L. Total, Dissolved, Free, Partial Zn(II) in mg/L
2- Exchange Areas	
3- Characteristic Length of Exchanges	
3- Segment volumes	
4- Waste loads for Cadmium	Total, Dissolved, Free, Partial Cd(II) in mg/L Dissolved Pb(II) in mg/L. Dissolved Zn(II) in mg/L
5- Waste loads for Lead	Total, Dissolved, Free, Partial Pb(II) in mg/L.

3.0 Results

Using the Report Generator in WASP we produced two sets of tables separated into the upper and lower segments of California Gulch. The first set of tables shows only the maximum difference for an individual value and the base case for each segment. The tables show the percentage difference between this extreme case and the baseline value. The second set of tables shows the maximum difference in the means for each segment and the base run. In the second set of tables, this difference is shown as a percentage of the base run.

3.1 Maximum Differences in Parameters by Segment

The maximum difference is for the base case entry (the first line of data for a give parameter), the percent difference is the greatest difference between all cases at every segment and time. This means that if at segment #2 at time 33 if there is a 1000% difference between its value and the base case and every other reading is identical to the base case, then the percent difference will be 1000%.

3.1.1 Adjusted Flows

All flows for each segment were adjusted by a percentage of the base value. The effect of applying different values for the flow and pore water flow on metal concentrations in segments (1 to 11) showed that the maximum change in concentration for Cd and Zn occurred when using 150% of the original value of the flow and pore water flow (Table 2). The change observed for Cadmium (Cd) did not appear to be a reasonable increase. Lead (Pb) experienced the maximum change at 25% of the original values of the flows, the change resulted in an increase in the concentration of lead.

TABLE 2. Maximum Changes Due to Adjusted Flows Relative to Base Case Values in Percentage for Segments 1-11, maximums are highlighted.

	Cadmium				Lead				Zinc			
Run	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	141.0	141.0	140.0	140.0	236.0	237.0	237.0	236.0	-100.0	-100.0	-100.0	-100.0
50%	-100.0	-100.0	-100.0	-100.0	82.1	82.8	82.2	81.6	-100.0	-100.0	-100.0	-100.0
75%	-100.0	-100.0	-100.0	-100.0	28.0	28.0	28.0	27.6	-71.9	-72.0	-72.0	-71.9
100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125%	3.8E+15	3.7E+15	3.7E+15	3.8E+15	-16.9	-17.2	-17.1	-17.2	50.2	50.2	50.7	50.4
150%	7.4E+15	7.4E+15	7.4E+15	7.4E+15	-28.0	-28.0	-28.0	-28.2	100.0	101.0	101.0	102.0

The effect of applying different values for the flow and pore water flow on metal concentrations in segments (12 to 22), showed the maximum change for Zn in all forms and dissolved Pb occurred when applying 150% of the original value of the flows (Table 3). Cadmium and other forms of lead the maximum change occurred at 25% of the original value of the flows with a resulting decreasing in concentration.

TABLE 3. Maximum Changes Due to Adjusted Flows Relative to Base Case Values in Percentage for Segments 12-22, maximums are highlighted.

	Cadmium				Lead				Zinc			
Run	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	-68.2	-68.2	-68.2	-68.3	11.2	-8.7	-8.5	-8.7	-72.9	-73.0	-73.0	-72.9
50%	-48.6	-48.7	-48.6	-48.8	-12.0	-5.7	-5.7	-6.0	-55.8	-55.9	-56.0	-55.9
75%	-25.7	-25.6	-25.6	-25.8	12.5	-3.0	-2.9	-3.4	-30.6	-30.7	-30.6	-30.6
100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125%	30.3	29.9	30.0	30.4	-13.4	3.0	2.9	2.8	35.0	35.1	35.0	35.0
150%	62.9	62.8	62.5	62.7	15.0	5.7	5.6	5.5	73.6	73.5	73.3	73.3

3.1.2 Exchange Areas

Pore exchange is controlled by two variables, the first is the area of contact between the upper and lower segments and the second variable is the characteristic length, see “Section 3.1.3: Exchange Characteristic Lengths”. The area between the upper and lower segments were changed simultaneously for all time periods.

The effect of applying different values for exchange areas on metal concentrations in segments (1 to 11) showed that the maximum change occurred when using 25% of the original value for all the metals. The change resulted in an increase in the concentration in the case of cadmium and zinc and a decrease in the case of lead. For the cadmium the percentage of change seems unreasonable (Table 4).

TABLE 4. Maximum Changes Due to Exchange Areas Relative to Base Case Values in Percentage for Segments 1-11, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	9.0E+15	9.0E+15	9.0E+15	9.0E+15	-63.9	-63.8	-63.8	-63.9	123.0	122.0	123.0	123.0
50%	6.0E+15	6.0E+15	5.9E+15	6.0E+15	-42.3	-42.3	-42.2	-42.5	85.0	85.1	85.8	84.6
75%	2.9E+15	2.9E+15	2.9E+15	2.9E+15	-20.9	-21.0	-21.0	-21.1	43.9	43.7	44.4	44.1
100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125%	-100.0	-100.0	-100.0	-100.0	26.3	26.1	26.2	26.6	-45.9	-46.0	-45.9	-45.9
150%	-100.0	-100.0	-100.0	-100.0	41.4	41.4	41.4	41.4	-91.7	-91.7	-91.7	-91.7

The effect of applying different values for exchange areas on metal concentrations in segments (12 to 22) showed that the maximum change for the Zn occurred when using 25% of the original value. The change resulted in an increase in the concentration in all the forms of Zn. For cadmium the maximum change occurred when applying 150% of the original value resulting in an increase in the concentration in all Cd forms. For lead the maximum change for concentration of dissolved Pb occurred when applying 150% of the base case, but for the other forms the maximum change occurred at 25% of the base case resulting in an increase for free Pb and decrease for part Pb, total Pb (Table 5).

TABLE 5. Maximum Changes Due to Exchange Areas Relative to Base Case Values in Percentage for Segments 12-22, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	12.2	12.1	12.1	11.8	-8.1	2.1	-2.0	-1.6	14.6	15.2	14.7	14.5
50%	9.0	8.3	8.7	8.7	11.9	1.4	1.3	-1.3	10.0	9.8	10.1	9.8
75%	4.9	4.7	4.8	4.8	12.5	0.7	-1.0	0.7	5.4	5.4	5.1	4.9
100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125%	6.4	6.4	6.4	6.6	-11.5	1.0	1.0	-0.7	-4.7	-4.6	-4.6	-4.7
150%	14.0	13.8	13.8	13.2	13.1	-1.4	-1.3	1.3	-8.5	-8.9	-8.7	-9.0

3.1.3 Exchange Characteristic Lengths

The characteristic length for exchanges in both the upper and lower segments were changed simultaneously to determine the values used in this sensitivity analysis. The effect of applying different values for the characteristic length for exchanges on metal concentrations in segments (1 to 11) showed that for zinc and lead the maximum change occurred when using 25% of the original value of the length of characteristic. The change resulted in an increase in concentration in the case of zinc and a decrease in the case of lead. With cadmium the maximum change occurred when applying 150% of original value of the length of characteristic but the increase in concentration was unreasonable (Table 6).

TABLE 6. Maximum Changes Due to the Characteristic Length of Exchanges Relative to Base Case Values in Percentage for Segments 1-11, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	**Free**	**Partial**	**Total**	**Dissolved**	**Free**	**Partial**	**Total**	**Dissolved**	**Free**	**Partial**	**Total**
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	339.0	340.0	339.0	340.0	347.0	348.0	348.0	348.0	509.0	506.0	508.0	508.0
50%	150.0	149.0	149.0	150.0	82.1	82.8	82.2	81.6	205.0	204.0	205.0	205.0
75%	-100.0	-100.0	-100.0	-100.0	27.8	28.0	28.0	27.6	-61.1	-61.1	-61.0	-61.1
100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125%	2.3E+15	2.3E+15	2.3E+15	2.3E+15	-17.6	-17.5	-17.5	-17.5	35.2	35.1	34.8	35.3
150%	3.9E+15	3.9E+15	3.9E+15	3.9E+15	-28.2	-28.0	-28.0	-28.2	58.1	57.9	58.2	58.0

The maximum change occurred when using 25% of the original value for the contact length of the exchanges for all most all of the metals, resulting in an increase in the concentration in Cd, Zn and Pb (Table 7). Dissolved lead experienced the maximum at 50% of the base case value.

TABLE 7. Maximum Changes Due to the Characteristic Length of Exchanges Relative to Base Case Values in Percentage for Segments 12-22, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	**Free**	**Partial**	**Total**	**Dissolved**	**Free**	**Partial**	**Total**	**Dissolved**	**Free**	**Partial**	**Total**
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	83.0	82.4	82.8	82.6	8.8	6.5	6.3	6.5	58.6	58.5	58.8	58.7
50%	29.0	29.4	28.9	28.3	13.1	-2.1	2.1	2.6	-16.2	-16.3	-16.5	-16.5
75%	9.0	8.8	8.9	9.0	12.0	1.0	1.0	1.1	-6.2	-6.3	-6.0	-6.2
100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125%	4.0	3.7	4.0	3.9	10.2	0.7	-1.0	0.7	3.9	4.5	4.1	3.8
150%	6.3	6.3	6.4	5.8	10.6	-1.0	-1.0	0.7	6.9	7.1	6.4	6.4

3.1.4 Volumes

The volumes of all segments were changed simultaneously to these values in this section. The volumes could not be run below 100% of the base value, since the model became unstable at the lower volumes.

The effect of applying different values for volumes on metal concentrations in segments (1 to 11) showed that maximum change in concentration for Cd and Zn occurred at 150% of the original value. The change resulted in a decrease in the case of Zn and an unreasonable increase in the case of Cd. Lead experienced the maximum change at 125% of the original value resulting in an increase in the concentration (Table 8).

TABLE 8. Maximum Changes in the Volumes Relative to Base Case Values in Percentage for Segments 1-11, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	-	-	-	-	-	-	-	-	-	-	-	-
50%	-	-	-	-	-	-	-	-	-	-	-	-
75%	-	-	-	-	-	-	-	-	-	-	-	-
100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125%	1.9E+14	1.9E+14	1.9E+14	1.9E+14	12.1	11.8	11.8	11.6	-23.0	-23.0	-23.3	-23.0
150%	3.7E+14	3.7E+14	3.7E+14	3.7E+14	-9.9	-9.8	-9.6	-9.7	-36.9	-37.0	-37.1	-37.0

The effect of applying different values for the characteristic length for exchanges on metal concentrations in segments (12 to 22) showed that maximum change in the concentration for Zn, Cd, Pb occurred when applying 150% of the original value of segments volume except for dissolved Pb its maximum change occurred at 125% of the original value. The change resulted in a decrease in concentration for all metals except for dissolved Pb the change was increase in the concentration.

TABLE 9. Maximum Changes in the Volumes Relative to Base Case Values in Percentage for Segments 12-22, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	-	-	-	-	-	-	-	-	-	-	-	-
50%	-	-	-	-	-	-	-	-	-	-	-	-
75%	-	-	-	-	-	-	-	-	-	-	-	-
100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125%	-25.2	-25.2	-25.2	-25.3	15.2	-2.2	-2.2	-2.7	-27.3	-27.4	-27.5	-27.3
150%	-40.4	-40.5	-40.3	-40.6	-7.7	-3.7	-3.9	-4.0	-43.5	-43.3	-43.7	-43.4

3.1.5 Cadmium Loading

The waste loads in the upper segments were changed for cadmium to evaluate model sensitivity. The effect of applying different values for waste loads for cadmium on metal concentrations in segments (1 to 11) showed that the maximum change in Cd concentration occurred when applying 50% of the original value of cadmium resulting in a decrease in concentration. All other metals had the maximum change at 150% of the original value of cadmium in waste loads, the change was increasing in concentration except for free and dissolved Pb experienced a decrease in concentration.

TABLE 10. Maximum Changes in Cadmium Loading values relative to Base Case Values in Percentage for Segments 1-11, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25%	1.9	2.1	2.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50%	-4.0	-4.0	-4.1	-4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
75%	1.7	1.8	1.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
125%	2.2	2.3	2.3	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150%	-1.8	-1.8	-2.2	-2.3	-0.1	-0.2	0.6	0.4	0.1	0.2	0.1	0.2

The effect of applying different values for waste loads for cadmium on metal concentrations in segments (12 to 22) showed that the maximum change for dissolved Pb and dissolved Zn occurred at 150% of the original value resulting in an increase in concentration. The maximum change for dissolved Cd occurred at 50% of the original value, resulting in an increase. Change in free and total Cd increased to maximum at 75% of the original value of cadmium in waste loads. At 25% of the original value cadmium experienced the maximum change resulting in a decrease in concentration.

TABLE 11. Maximum Changes in Cadmium Loading values relative to Base Case Values in Percentage for Segments 12-22, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	0.0	0.0	0.0	0.0	0.0	-	-	-	0.0	-	-	-
25%	0.4	0.0	-0.1	0.0	0.0	-	-	-	0.0	-	-	-
50%	0.7	0.0	-0.1	0.0	0.0	-	-	-	0.0	-	-	-
75%	0.7	0.2	0.0	0.1	0.0	-	-	-	0.0	-	-	-
100%	0.0	0.0	0.0	0.0	0.0	-	-	-	0.0	-	-	-
125%	-0.7	0.0	0.1	0.0	0.0	-	-	-	0.0	-	-	-
150%	-0.4	0.0	0.1	0.0	2.9	-	-	-	0.6	-	-	-

3.1.6 Lead Loading

The waste loads in the upper segments were changed for lead to evaluate model sensitivity. The effect of applying different values for waste loads for lead on metal concentrations in segments (1 to 11) showed that maximum change occurred when applying 150% of the original value of Pb in waste loads the change was a decrease in total Pb, free Pb but concentration increased for dissolved Pb and part Pb.

TABLE 12. Maximum Changes in Lead Loading values relative to Base Case Values in Percentage for Segments 1-11, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	-	-	-	-	0.0	0.0	0.0	0.0	-	-	-	-
25%	-	-	-	-	-0.5	-0.3	-0.2	-0.3	-	-	-	-
50%	-	-	-	-	-0.5	-0.3	-0.2	-0.3	-	-	-	-
75%	-	-	-	-	-0.5	-0.3	-0.2	-0.3	-	-	-	-
100%	-	-	-	-	0.0	0.0	0.0	0.0	-	-	-	-
125%	-	-	-	-	0.0	0.0	0.2	0.3	-	-	-	-
150%	-	-	-	-	0.9	-0.3	0.2	-0.3	-	-	-	-

The effect of applying different values for waste loads for lead on metal concentrations in segments (12 to 22) showed that the maximum change occurred at 150% of the original value of Pb in waste loads for dissolved Pb and was a decrease in concentration.

TABLE 13. Maximum Changes in Lead Loading values relative to Base Case Values in Percentage for Segments 12-22, maximums are highlighted.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	-	-	-	-	0.0	-	-	-	-	-	-	-
25%	-	-	-	-	0.2	-	-	-	-	-	-	-
50%	-	-	-	-	0.2	-	-	-	-	-	-	-
75%	-	-	-	-	0.0	-	-	-	-	-	-	-
100%	-	-	-	-	0.0	-	-	-	-	-	-	-
125%	-	-	-	-	0.0	-	-	-	-	-	-	-
150%	-	-	-	-	-0.7	-	-	-	-	-	-	-

3.2 Comparison of Mean Values

For this section the means over the time periods for each segment were compared to establish the maximum numerical difference from the base case in the means. This comparison was made to establish changes in typical values to complement the presentation of the maximum individual differences in section "Section 3.1: Maximum Differences in Parameters by Segment". The following tables present these values as percentages.

3.2.1 Adjusted Flows

Adjusted flows showed the maximum decrease in concentrations for cadmium and zinc at 25% of the base values, and at 150% for lead for segments 1-11. The maximum increases occurred at 150% for zinc and cadmium and at 25% for lead (Table 14).

TABLE 14. Comparison of mean values for adjusted flows for segments 1-11, maximums are shaded and minimums are in bold.

	Cadmium				**Lead**				**Zinc**			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
25%	**52%**	**52%**	**78%**	**52%**	194%	315%	292%	292%	**40%**	**40%**	**48%**	**40%**
50%	67%	67%	83%	67%	139%	174%	166%	166%	61%	61%	64%	13%
75%	83%	83%	91%	83%	114%	125%	122%	122%	81%	80%	82%	58%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
125%	117%	117%	110%	117%	92%	91%	87%	87%	120%	120%	119%	141%
150%	135%	135%	121%	135%	**86%**	**76%**	**78%**	**78%**	141%	141%	138%	181%

In segments 12-22 the maximum decrease occurred at 25% of the base value for all metals. The maximum increase occurred at 150% for all metals except for free lead and that was at 125% (Table 15).

TABLE 15. Comparison of mean values for adjusted flows for segments 12-22, maximums are shaded and minimums are in bold.

	Cadmium				**Lead**				**Zinc**			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
25%	**41%**	**41%**	**41%**	**41%**	**95%**	**95%**	**96%**	**95%**	**32%**	**32%**	**37%**	**32%**
50%	61%	61%	58%	58%	97%	97%	97%	97%	55%	55%	52%	55%
75%	81%	81%	77%	77%	98%	98%	99%	99%	78%	78%	73%	78%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
125%	118%	119%	127%	127%	101%	102%	101%	102%	121%	121%	131%	121%
150%	156%	156%	156%	156%	103%	101%	102%	104%	142%	142%	164%	142%

3.2.2 Exchange Areas

Changing the exchange area for segments 1-11 showed the maximum increase occurred at 25% of the base value for cadmium and zinc, and at 150% for leads. The maximum decrease occurred for cadmium at 125%, zinc at 150%, and for lead at 25% of the base value.

TABLE 16. Comparison of mean values for exchange areas for segments 1-11, maximums are shaded and minimums are in bold.

	Cadmium				**Lead**				**Zinc**			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
25%	581%	580%	584%	581%	**60%**	**75%**	**48%**	**48%**	173%	149%	154%	155%
50%	412%	412%	414%	413%	75%	84%	65%	66%	133%	133%	135%	133%
75%	239%	239%	240%	239%	88%	92%	83%	83%	117%	117%	117%	117%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
125%	**104%**	**104%**	**101%**	**104%**	111%	107%	117%	117%	83%	83%	83%	83%
150%	109%	108%	102%	108%	121%	114%	133%	133%	**66%**	**66%**	**66%**	**66%**

Changing the exchange area for segments 12-22 showed the maximum increase occurred at 150% of the base value for cadmium and zinc. The maximum decrease occurred for cadmium and zinc at 25%. The response of lead was more complex. There was no maximum for partial lead and the maximum occurred between 25-75% for dissolved, free and total lead. There was no minimum for dissolved lead and the minimum for partial was 25-50%. For free and total lead the maximum decrease was between 125-150%.

TABLE 17. Comparison of mean values for exchange areas for segments 12-22, maximums are shaded and minimums are in bold.

	Cadmium				**Lead**				**Zinc**			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
25%	**90%**	**90%**	**90%**	**90%**	101%	101%	**99%**	101%	**90%**	**90%**	**90%**	**90%**
50%	94%	94%	94%	94%	100%	101%	**99%**	101%	93%	93%	93%	93%
75%	97%	97%	97%	97%	100%	100%	100%	101%	97%	97%	97%	97%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
125%	105%	105%	105%	105%	100%	**99%**	100%	100%	103%	103%	103%	103%
150%	111%	111%	111%	111%	100%	**99%**	100%	**99%**	106%	106%	106%	106%

3.2.3 Exchange Characteristic Lengths

Changing the characteristic length of exchanges for segments 1-11 showed the maximum increase occurred at 150% of the base value for cadmium and zinc, and at 25% for lead. The maximum decrease occurred for zinc at 25% and for lead at 150% of the base value. Cadmium did not experience a decrease in the mean values from the base value by the lowest increase occurred at 75% of the base value.

TABLE 18. Comparison of mean values for characteristic length of exchange for segments 1-11, maximums are shaded and minimums are in bold.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
25%	136%	136%	108%	136%	208%	166%	286%	286%	**7%**	**7%**	**7%**	**7%**
50%	116%	116%	104%	116%	140%	127%	166%	166%	35%	35%	35%	35%
75%	**105%**	**106%**	**101%**	**106%**	115%	110%	122%	123%	78%	78%	78%	78%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
125%	204%	204%	205%	204%	90%	94%	86%	86%	113%	113%	113%	113%
150%	297%	297%	298%	297%	**84%**	**90%**	**77%**	**77%**	122%	122%	122%	122%

Changing the characteristic length of the exchange area for segments 12-22 showed the maximum increase occurred at 25% of the base value for cadmium and zinc. The maximum decrease occurred at 150% for cadmium and zinc. Lead showed a complex response with no increases except for total and partial lead, at 125-150% and, 25% respectively. The maximum decrease occurred for lead at 25% of the base case value except for partial lead which occurred at 150%.

TABLE 19. Comparison of mean values for characteristic length of exchange for segments 12-22, maximums are shaded and minimums are in bold.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
25%	171%	171%	171%	171%	**97%**	**97%**	103%	**97%**	153%	153%	152%	153%
50%	123%	123%	123%	123%	99%	99%	101%	99%	112%	113%	113%	113%
75%	107%	107%	107%	107%	100%	99%	100%	100%	104%	104%	104%	104%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
125%	97%	97%	97%	97%	100%	100%	100%	101%	97%	98%	97%	97%
150%	**96%**	**96%**	**96%**	**96%**	100%	100%	**99%**	101%	**96%**	**96%**	**96%**	**96%**

3.2.4 Volumes

Volumes could only be changed for values of 100% or greater for volumes. Increasing the volumes for segments 1-11 resulted in decreased the concentrations in all cases with the maximum decrease occurring at 150% of the base value for all metal forms.

TABLE 20. Comparison of mean values for volumes for segments 1-11, minimums are in bold.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
25%	-	-	-	-	-	-	-	-	-	-	-	-
50%	-	-	-	-	-	-	-	-	-	-	-	-
75%	-	-	-	-	-	-	-	-	-	-	-	-
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
125%	83%	83%	87%	83%	99%	97%	98%	98%	81%	80%	83%	80%
150%	72%	72%	79%	72%	97%	95%	96%	97%	69%	68%	72%	67%

Increasing the volumes for segments 12-22 resulted in decreased the concentrations in all cases with the maximum decrease occurring at 150% of the base value for all metal forms.

TABLE 21. Comparison of mean values for volumes for segments 12-22, minimums are in bold.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
25%	-	-	-	-	-	-	-	-	-	-	-	-
50%	-	-	-	-	-	-	-	-	-	-	-	-
75%	-	-	-	-	-	-	-	-	-	-	-	-
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
125%	85%	85%	78%	78%	100%	99%	**99%**	99%	83%	83%	76%	83%
150%	**75%**	**75%**	**65%**	**65%**	**100%**	**98%**	**99%**	**98%**	**71%**	**71%**	**62%**	**71%**

3.2.5 Cadmium Loading

The waste loads in the upper segments were changed for cadmium to evaluate model sensitivity. The effect of applying different values for waste loads for cadmium on metal concentrations in segments (1 to 11) showed no significant change in cadmium or dissolved lead.

TABLE 22. Comparison of mean values for increases in cadmium waste loads for segments 1-11, minimums are in bold.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	-	-	-	-	-	-	-
25%	100%	100%	101%	100%	100%	-	-	-	-	-	-	-
50%	100%	100%	100%	100%	100%	-	-	-	-	-	-	-
75%	100%	100%	101%	100%	100%	-	-	-	-	-	-	-
100%	100%	100%	100%	100%	100%	-	-	-	-	-	-	-
125%	100%	100%	101%	100%	100%	-	-	-	-	-	-	-
150%	100%	100%	100%	100%	100%	-	-	-	-	-	-	-

The effect of applying different values for waste loads for cadmium on metal concentrations in segments (12 to 22) showed no change in cadmium or dissolved lead.

TABLE 23. Comparison of mean values for increases in cadmium waste loads for segments 12-22, minimums are in bold.

	Cadmium				Lead				Zinc			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	100%	100%	100%	100%	100%	-	-	-	-	-	-	-
25%	100%	100%	100%	100%	100%	-	-	-	-	-	-	-
50%	100%	100%	100%	100%	100%	-	-	-	-	-	-	-
75%	100%	100%	100%	100%	100%	-	-	-	-	-	-	-
100%	100%	100%	100%	100%	100%	-	-	-	-	-	-	-
125%	100%	100%	100%	100%	100%	-	-	-	-	-	-	-
150%	100%	100%	100%	100%	100%	-	-	-	-	-	-	-

3.2.6 Lead Loading

The waste loads in the upper segments were changed for lead to evaluate model sensitivity. The effect of applying different values for waste loads for lead on metal concentrations in segments (1 to 11) showed no significant change in lead.

TABLE 24. Comparison of mean values for increases in lead waste loads for segments 1-11, minimums are in bold.

	Cadmium				**Lead**				**Zinc**			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	-	-	-	-	100%	100%	100%	100%	-	-	-	-
25%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
50%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
75%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
100%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
125%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
150%	-	-	-	-	100%	100%	100%	100%	-	-	-	-

The waste loads in the upper segments were changed for lead to evaluate model sensitivity. The effect of applying different values for waste loads for lead on metal concentrations in segments (12 to 22) showed no significant change in lead.

TABLE 25. Comparison of mean values for increases in lead waste loads for segments 12-22, minimums are in bold.

	Cadmium				**Lead**				**Zinc**			
	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total	Dissolved	Free	Partial	Total
Base	-	-	-	-	100%	100%	100%	100%	-	-	-	-
25%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
50%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
75%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
100%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
125%	-	-	-	-	100%	100%	100%	100%	-	-	-	-
150%	-	-	-	-	100%	100%	100%	100%	-	-	-	-

4.0 Analysis

This section will describe some of the trends in the sensitivity analysis and how changes in parameters changed the extreme values in “Section 3.1: Maximum Differences in Parameters by Segment” and the average values presented in “Section 3.2: Comparison of Mean Values”. Segments 1-11 are for surface water (upper) and segments 12-22 are for the pore or groundwater segments (lower).

4.1 Adjusted Flows

Cadmium resulted in extremely high individual values for the upper segments when flows were increased, however the mean values showed a more consistent trend as shown in Figure 1. Cadmium and Zinc generally decreased in both the upper and lower segments with decreased flows and increased with increasing flows. Lead showed the opposite relationship in the upper segments and the same relationship in the lower segments.

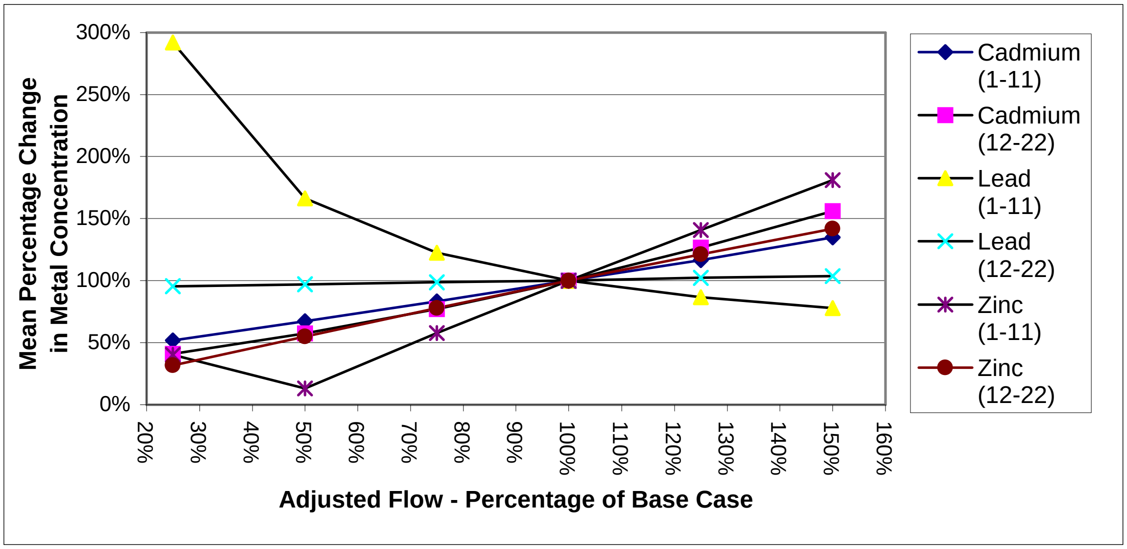

Figure 1: Maximum Changes in Mean Total Metal Concentrations for Adjusted Flows.

4.2 Exchange Areas

Cadmium resulted in extremely high individual values for the upper segments when exchange area is decreased, however the mean values showed a more consistent trend as shown in Figure 1. Cadmium and Zinc generally decreased in both the upper and lower segments with decreased flows and increased with increasing flows. Lead showed the opposite relationship in the upper segments and the same relationship in the lower segments.

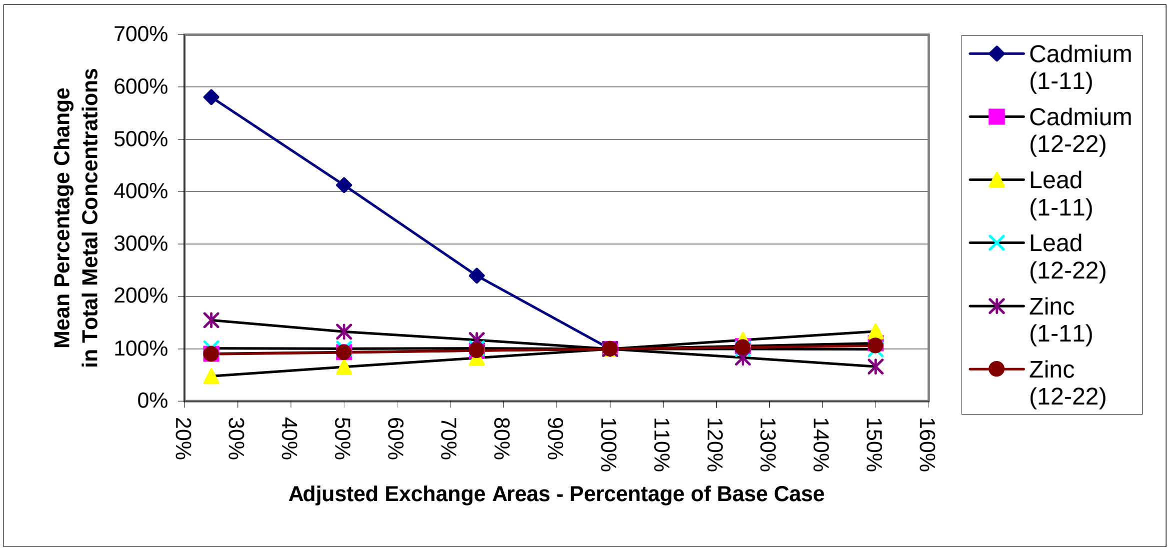

Figure 2: Maximum Changes in Mean Total Metal Concentrations for Adjusted Exchange Areas.

4.3 Exchange Characteristic Lengths

Increasing the characteristic lengths for the exchange areas resulted in increases in cadmium and zinc, but decreases in lead concentrations for segments 1-11. Again, the metals resulted in the opposite reaction for reductions in characteristic lengths. Zinc experience very high individual values (Table 6) yet a reduction in the mean values (Table 18). Zinc and cadmium had the opposite reaction to changes in characteristic lengths in the lower segments (12-22).

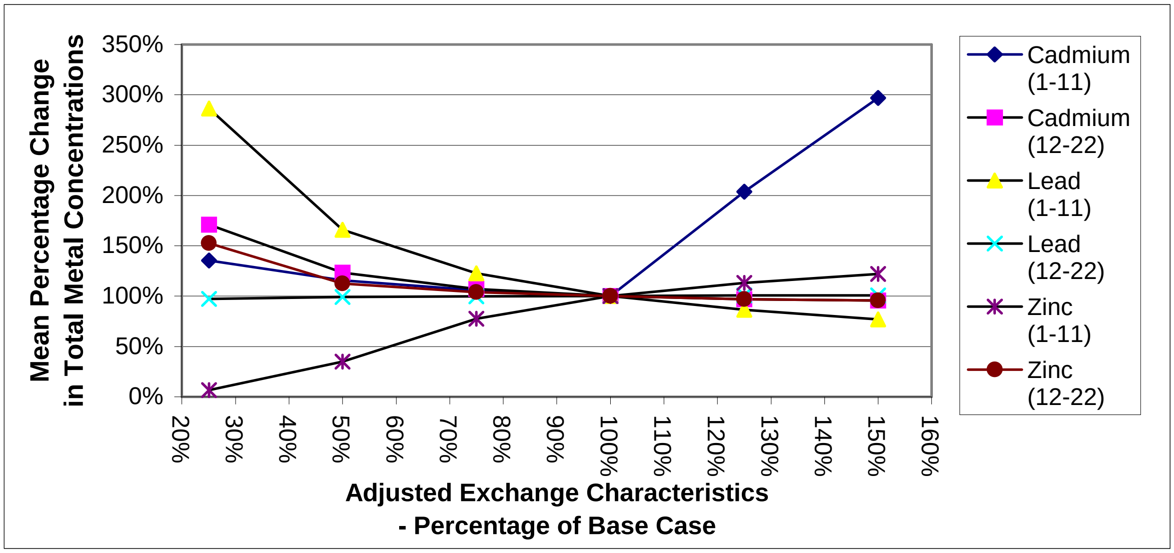

Figure 3: Maximum Changes in Mean Total Metal Concentrations for Adjusted Characteristic Lengths.

4.4 Volumes

Since the model became unstable for volumes below the base case only increases in volume could be looked at. All the metals experienced decreases as volume increased and cadmium experience unreasonable increases for high individual values.

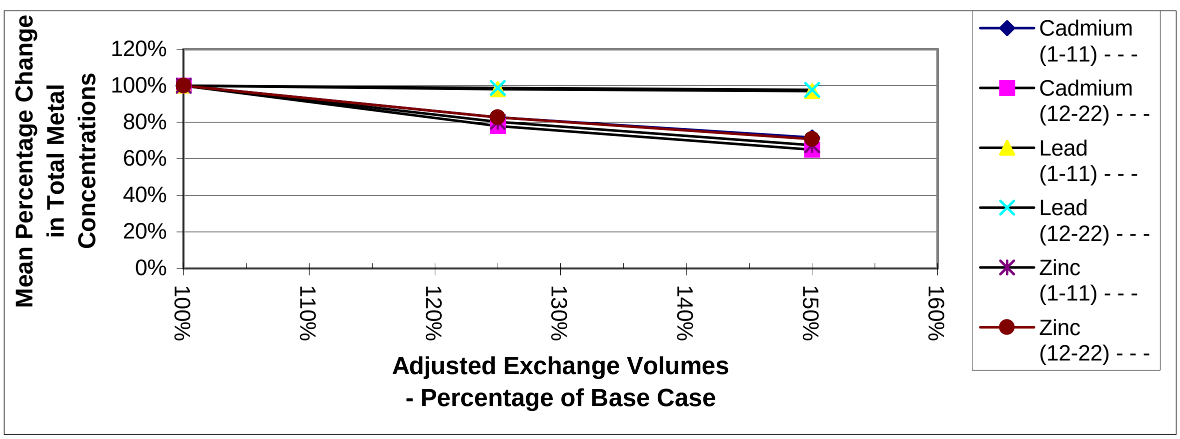

Figure 4: Maximum Changes in Mean Total Metal Concentrations for Adjusted Volumes.

4.5 Cadmium and Lead Loading

No changes were observed in the mean values for metal concentrations by increasing or decreasing waste loads into the system. This may indicate a problem in the model. There were changes in individual values, but in some cases increasing the loading of cadmium resulted in decreases in individual values (Table 10 and Table 11). The same kind of behavior was observed for lead (Table 12 and Table 13).

5.0 Conclusions

The sensitively analysis showed that some individual values can become extremely high with changes in model parameters (such as cadmium) and the model did not seem to be at all sensitive to waste loads, which seems odd. For the most part mean values seemed to show more consistent trends. Cadmium and Zinc responded in similar fashions in these trends, with lead nearly always showing the opposite relationship to adjustments in parameters. The most sensitive parameter is exchange areas resulting in nearly a 600% increase in cadmium when reduced to 25% of the base value (Table 16). As noted before, waste loads are the least sensitive parameter and many of the individual values for cadmium appeared unreasonably high.